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Rolling down from the 30 keV peak

Modelling the hard X-ray and γ -ray backgrounds

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Abstract We will briefly discuss the importance of sensitive X-ray observations above a few tens of keV for a better understanding of the physical mechanisms associated to the Supermassive Black Hole primary emission in both radio quiet and radio loud AGN and to the cosmological evolution of the most obscured sources.

Keywords X-rays · background radiation · AGN

1 Introduction

The fraction of the hard X-ray background (XRB) resolved into discrete sources by deep *Chandra* and XMM-*Newton* observations smoothly decreases from essentially 100 % below 2–3 keV to about 50% in the 7–10 keV energy range (Worsley et al. 2005). The resolved fraction averaged on the standard 2–10 keV band is of the order of 80% (see Hickox & Markevitch 2006 for a recent estimate). At energies greater than 10 keV, where the bulk of the

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background energy density is produced, the resolved fraction is negligible, being strongly limited by the lack of imaging X-ray observations.

The energy dependence of the resolved fraction goes almost hand in hand with the self-consistency of AGN synthesis models. While at relatively low energy (say below 8–10 keV) a robust model, build over the AGN unified scheme, precisely account for a large body of observational data (XRB spectral intensity, X-ray source counts, redshift distribution, etc.) at higher energies the predictive power is strongly limited by the lack of observational constraints.

At present the best estimates of the key parameters, responsible of the XRB spectral intensity around and above the 30 keV peak, mainly rely on the observations obtained with the *PDS* instrument onboard *BeppoSAX* (Risaliti et al. 1999; Matt 2004) and are thus limited to nearby bright ($S_{10-100\text{keV}} > 10^{-11} \text{ erg cm}^{-2} \text{ s}^{-1}$) objects. As a consequence a relatively wide portion of the model parameter space remains so far unexplored (e.g. Comastri 2004a).

2 XRB modelling

Within the framework of AGN synthesis models the key parameters responsible for the shape and intensity of the $> 10 \text{ keV}$ XRB spectrum are:

- the covering fraction and geometrical distribution of the cold dense gas responsible of the reflection "hump" peaking at 20–30 keV and observed in both type 1 and type 2 AGN.
- the relative fraction of heavily obscured sources with column densities of the order of a few 10^{24} cm^{-2} (the so called "mildly" Compton thick AGN; see Comastri 2004b for a review).
- the high energy cut-off of the primary emission which is usually parameterized as an exponential roll-over with an e-folding energy of a few hundreds of keV.

The reflection of hard X-rays by cold dense circumnuclear gas is a well established property of nearby Seyfert galaxies (see Pounds et al. 1990 for the discovery *Ginga* observations and Perola et al. 2002 for a spectral survey of bright AGN with *BeppoSAX*). For unobscured or relatively unobscured AGN the reflecting material is covering about $2\pi \text{ sr}$.

Several independent observational evidences suggest that a fraction as large as 50% (or even higher) of the Seyfert 2 galaxies in the local Universe are obscured by Compton-thick material (Risaliti et al. 1999; Guainazzi et al. 2005; Comastri 2004b). A population of Compton thick (hereinafter CT) sources has to be included in AGN synthesis models for the XRB in order to match the 30 keV intensity peak and at the same time to avoid an excessive number of Compton thin AGN which are not detected in *Chandra* and XMM-*Newton* deep surveys (see the discussion in Comastri 2004b). Their relative fraction and cosmological evolution are free parameters which are tuned until a good fit to the XRB spectrum is obtained.

Assuming the same cosmological evolution of soft X-ray selected type 1 AGN of Hasinger et al. (2005), the best fit model shown in Figure 1 is

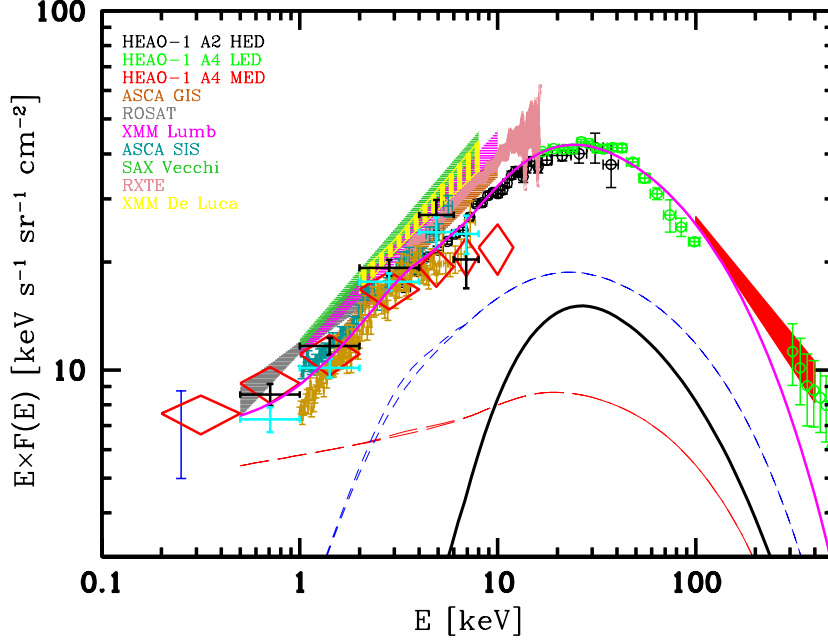


Fig. 1 The cosmic XRB spectrum and predicted AGN contribution (magenta solid line which includes also galaxy clusters) splitted between unobscured (red dashed line), Compton thin (blue thin line) and Compton thick (black line). For unobscured and Compton thin AGN the effect of including iron line emission is also reported and corresponds to the upper red and blue dashed curve (Gilli et al. 1999). The different XRB measurements are explained on the top left. Also shown are the resolved XRB fractions in different surveys by Worsley et al. (2005): Lockman Hole = red diamonds; CDFS = cyan crosses; CDFN = black crosses.

obtained with a relative fraction of CT AGN which is the same of Compton thin (N_H in the range 10^{22} – 10^{24} cm^{-2}) and twice than unobscured ($N_H < 10^{22}$ cm^{-2}) AGN (see Gilli et al 2006 for further details). The peaked shape of the CT spectrum in a $\nu F_\nu - \nu$ plot is due to heavy absorption at low energies and the high energy cut-off (E_{cut}). The latter, fixed at 320 keV in Fig. 1, has to be present in the high energy spectrum of all the sources (regardless of the absorption column density) otherwise the observed XRB flux above about 100 keV would be exceeded.

The high energy cut-off e-folding energy has been unambiguously measured only for a bunch of nearby Seyfert galaxies. The best fit values are loosely constrained in the 150–350 keV range (Matt 2004; Malizia et al.

2003). Both BeppoSAX (Matt et al. 1999) and more recent *INTEGRAL* observations (Soldi et al. 2005) suggest a large scatter in the E_{cut} values which span from about 50 keV up to lower limits of the order of 500 keV. While a clear bias against large values of the high energy cut-off is present, the available observations seem to indicate that such a parameter might not be the same in all the sources at variance with the assumptions of most of the synthesis models.

The properties of the sources of the "unresolved" background may be inferred by subtracting from the observed broad band spectrum the energy dependent fraction of the "resolved" XRB. Such an approach has been pursued both making use of present observations (Worsley et al. 2005) and exploiting the XRB synthesis models (Comastri 2004). In the former case the spectral shape of the "unresolved" background is consistent with that expected from a population of obscured ($N_H \simeq 10^{23-24} \text{ cm}^{-2}$) AGN at redshifts $\sim 0.5-1.5$. In the latter, following a model dependent approach, the shape of the unresolved fraction can be predicted over a much wider energy range. More specifically assuming a set of model parameters tuned to match the 2–10 keV resolved fraction and to reproduce the observed absorption distribution in deep fields the predicted XRB flux and spectral shape above 10 keV are strongly dependent from the adopted of E_{cut} value (see Fig. 2 in Comastri 2004a).

3 Exploring the parameter space

An additional source of uncertainties comes from the possible contribution to the hard XRB / soft γ -ray backgrounds (above about 100 keV) of the population of radio-loud sources which includes, for the purposes of the present exercise, both flat spectrum radio quasars (e.g. 3C 273) and BL Lac objects. We refer to Giommi et al. (2006 and these proceedings) for a detailed discussion of their contribution to the extragalactic X-ray and γ -ray bands. In the very first approximation radio-loud sources are expected to provide the bulk of the γ -ray background above a few tens of MeV, while radio-quiet AGN dominate below 100 keV. In between their relative contribution is expected to be comparable. An attempt to estimate the contribution of radio-loud quasars to the X-ray/soft γ -ray background (from 1 keV to a few MeV) is presented here. The assumed template spectrum and cosmological evolution are as follows:

- the average X-ray/ γ -ray spectrum is parameterized with a single power law plus a high energy cut-off.
- the input spectrum is then folded with the same luminosity function of radio-quiet AGN assuming a pure luminosity evolution of the form $L(z) \propto L(0) \times (1+z)^3$ normalized to account for 10% of the XRB flux at 1 keV in agreement with Giommi et al. (2006) and Galbiati et al. (2005).

The power law slope energy index α is varied in the range 0.5–0.7 consistent with the averaged value observed in the X-ray band over a large range of redshifts (i.e. Reeves & Turner 2000; Page et al. 2005; Lopez et al. 2006),

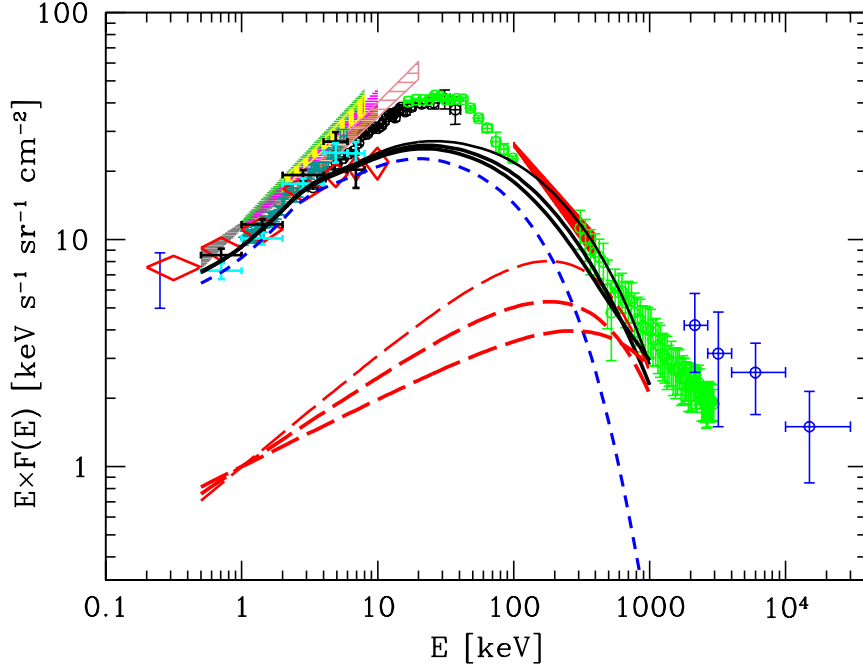


Fig. 2 An estimate of the radio loud AGN contribution to the XRB computed for a range of slopes and high energy cut-offs (red long-dashed lines; see details in the text). The blue short dashed line represents the so far resolved fraction modeled following the prescriptions of Gilli et al. 2006. The solid black lines are the sum of the above mentioned components

while the choice of the E_{cut} value is driven by the requirement of not exceeding the background flux. The results for three representative pairs of α and E_{cut} : (0.5 , 800 keV); (0.6 , 1 MeV) and (0.7 , 2 MeV) are shown in Figure 2 (long dashed lines from top to bottom respectively). In our approach, almost by definition, the two parameters are not completely independent, the flatter the power law slope, the lower the cut-off energy is. The contribution of radio loud AGN is then summed to the observationally resolved fraction in the 2–10 keV range, extrapolated to high energies following the prescriptions of the Gilli et al. (2006) model (short dashed line in Fig. 2). Finally the total contribution for the three α , E_{cut} pairs is computed (solid lines).

The residual unresolved background obtained by subtracting the models previously described from the total XRB flux, modeled using the Gruber (1992) analytical approximation, is shown in Figure 3. A comparison with the contribution of a population of CT AGN, assumed to evolve as unobscured sources (Hasinger et al. 2005), for two different values (100 and 320 keV) of the high energy cut-off is shown in Fig. 4. The model spectra agree extremely well below the peak energy while at higher energies, depending from the E_{cut} and α values adopted to model the contribution of radio-loud AGN, the predicted residual spectrum falls more rapidly with an over-exponential

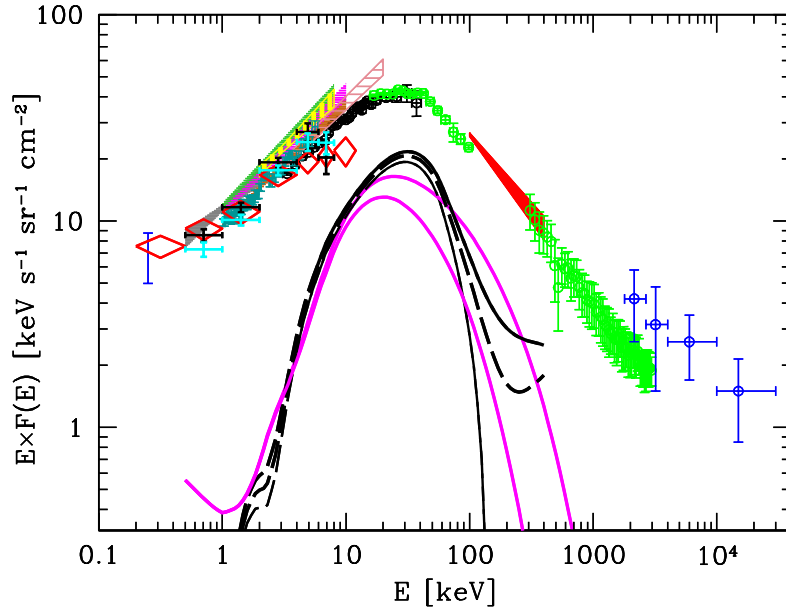


Fig. 3 The unresolved background as obtained by subtracting the contribution of both radio-quiet and radio-loud AGN (long-dashed black lines) along with that predicted by the CT AGN in the Gilli et al. 2006 model for two different E_{cut} values (magenta solid lines). The XRB spectral data in the 0.3–3 MeV range are from SMM (Watanabe et al. 1997), while in the 2–30 MeV from COMPTEL (Kappadath et al. 1996)

shape which is more pronounced for $\alpha=0.5$, $E_{cut}=800$ keV. At the face value these results suggest that the sources of the unresolved background are characterized by either a very peaked spectrum or are clustered over a smaller redshift range or a combination of the two.

4 Conclusions

The above described exercise confirm and somewhat extend the findings of Worsley et al (2005) and Comastri (2004a). Even though the model dependent approach does not allow to break the degeneracy between the spectral parameters and in particular among the cut-off energy and the source redshift some preliminary conclusions may be already drawn. A population of CT AGN with a space density and cosmological evolution comparable to that of less obscured, Compton thin sources provide an excellent description of the residual XRB spectrum up to about 10–20 keV. At higher energies the residual spectrum is no longer well approximated by an exponentially cut-off power law model folded with the redshift distribution observed in deep *Chandra* and *XMM-Newton* fields. It can be argued that a suitable fine tuning of cut-off energy and redshift distributions along with a more extended treatment of the contribution of radio-loud AGN may provide a

much better fit to the unresolved XRB above 30 keV. However it should be also stressed that the observational constraints used to compute the residual XRB are still subject to significant uncertainties. Recent measurements of the XRB spectral intensity below 10 keV obtained with imaging instrument are systematically higher than the intensity originally measured by HEAO1-A2 (see Fig. 1 and Revnivtsev et al. 2005 for a recent reanalysis of the HEAO1 data). Given that the only available observation of the intensity and location of the XRB peak is from the same A2 experiment, some doubts have been raised on the absolute flux and intensity of the XRB above 10 keV. In the hard X-rays/ soft γ -rays the statistical errors as well as the relative calibration between different experiments are even larger. Before attempting a more sophisticated modelling of the broad band background spectrum from its peak down to MeV and GeV region a more robust determination of the observational framework is needed. Sensitive imaging observations down to about 10^{-14} erg cm $^{-2}$ s $^{-1}$ in the approximately 10–50 keV energy range would resolve about half of the background in that band to be compared with the present less than a few percent. A major breakthrough in the census and the study of obscured accreting black holes is expected by future hard X-ray missions and especially by Simbol-X (Ferrando et al. 2005). A mission capable to explore the 100–1000 keV decade with comparably good sensitivity (i.e. the Gamma Ray Imager mission concept see Von Ballmoos and Knödlseeder these proceedings) would open the possibility to investigate the origin of the primary emission mechanism in AGN, presumably responsible of the high energy cut-off, with important consequences for the scientific objectives discussed in this paper.

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